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Determination of Optimal Toxicant Loading for Biological Closure of a Hazardous Waste Site

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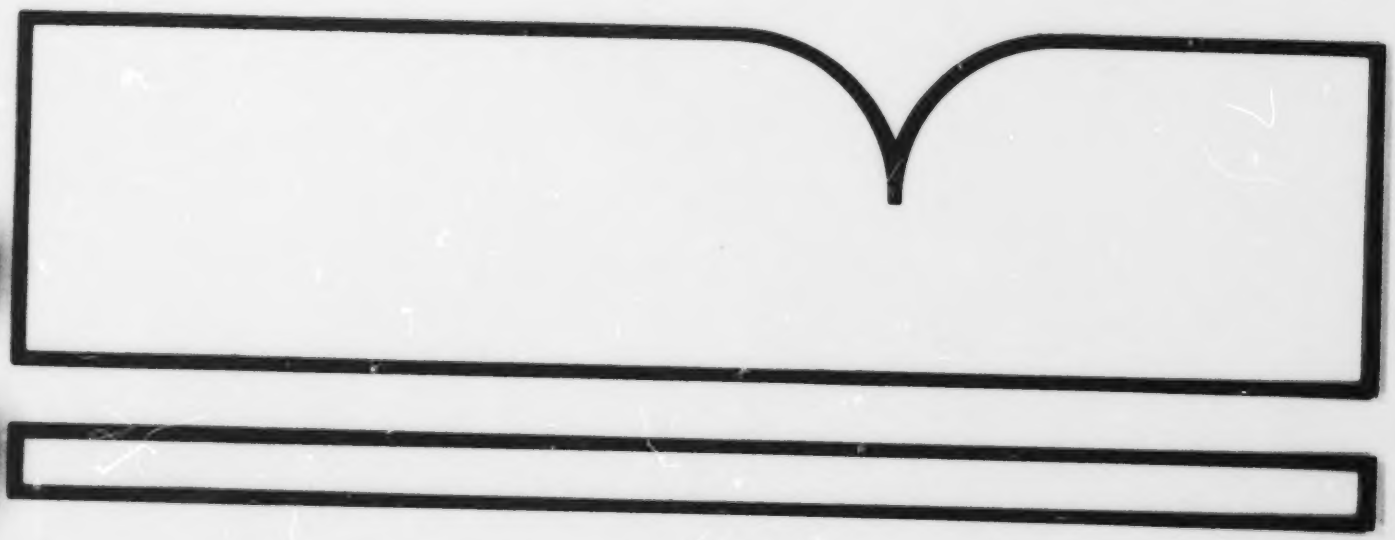

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16. ABSTRACT

Information on Phase I and Phase II of a multitask effort to achieve biological closure of an abandoned hazardous waste site. Waste materials, in the form of buried sludges and lagoon wastes, were examined. Optimal loading levels were evaluated on the basis of biodegradative potential tests and acute toxicity of leachate. Microbial ATP and microbial diversity were used in conjunction with Microtox (tm) tests to establish an acceptable land treatment experimental design. ATP data indicated that both waste types stressed indigenous microbial populations through Day 10. However, the microbial population showed recovery by Day 17. Lagoon wastes, applied at 4 and 8%, showed minimal stress and high ATP levels by Day 17. Buried wastes showed comparable results for 2 to 4% waste loadings at Day 17. Microbial diversity indices confirmed ATP estimates, which suggested a maximum loading rate of 8% for lagoon wastes and 2 to 4% for buried wastes. EC_{50} levels of leachates predicted 3.0 to 6% waste weight (wet basis) for buried waste. A loading rate of 4% for lagoon waste and 2.5% for buried waste was selected as the acceptable mean loading rate. GC/MS data in subsequent Phase II studies documented significant biotransformation and biodegradation of the wastes at these optimized loading rates. → Con't on Pg 503

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Determination of Optimal Toxicant Loading for Biological Closure of a Hazardous Waste Site

REFERENCE: Bianchini, M. A., Portier, R. J., Fujisaki, K., Henry, C. B., Templet, P. H., and Matthews, J. E., **"Determination of Optimal Toxicant Loading for Biological Closure of a Hazardous Waste Site,"** *Aquatic Toxicology and Hazard Assessment: 10th Volume, ASTM STP 971*, W. J. Adams, G. A. Chapman, and W. G. Landis, Eds., American Society for Testing and Materials, Philadelphia, 1988, pp. 503–516.

ABSTRACT: Information will be presented on Phase I and Phase II of a multitask effort to achieve biological closure of an abandoned hazardous waste site on the Mississippi River. Waste materials, consisting primarily of aliphatic and polycyclic aromatic hydrocarbons in the form of buried sludges and lagoon wastes, were examined. Optimal loading levels were evaluated on the basis of biodegradative potential tests and acute toxicity of leachate. Microbial adenosine 5′ triphosphate (ATP) and microbial diversity were used in conjunction with Microtox® tests to establish an acceptable land treatment experimental design. Methodology is presented on ascertaining optimal waste loading rates, based on percent oil and grease, for both laboratory mesocosm and field plots. Microbial ATP data indicated that both waste types stressed the indigenous microbial populations through Day 10. However, the microbial population showed recovery by Day 17. Lagoon wastes, applied at 4 and 8%, showed minimal stress and high microbial ATP levels by Day 17. Buried wastes showed comparable results for 2 to 4% waste loadings at Day 17. Microbial diversity indices confirmed ATP estimates, which suggested a maximum loading rate of 8% for lagoon wastes and 2 to 4% for buried wastes. EC_{50} levels of leachates predicted 3.0 to 9.0% waste weight (wet basis) for lagoon waste and 3.0 to 6% waste weight (wet basis) for the buried waste. A loading rate of 4% for lagoon waste and 2.5% for buried waste was selected as the acceptable mean loading rate. Gas chromatography/mass spectroscopy (GC/MS) data in subsequent Phase II studies (mesocosms) documented significant biotransformation and biodegradation of the wastes at these optimized loading rates.

KEYWORDS: biodegradation, biotransformation, polycyclic aromatic hydrocarbons (PAHs), *in situ* biological treatment (ISBT)

Industrialized deltas often have the combined problems of improper land management and unwise water resource allocation. Significant threats to both surface and groundwater supplies are posed by the location of numerous hazardous waste sites in close proximity to commercial activities. A case in point is the industrialized lower delta of the Mississippi River in Louisiana. Noteworthy strides have been made along this "chemical corridor" in reducing waste discharges into the Mississippi River. However, many abandoned refineries, hazardous waste pits, and pipelines remain. These facilities represent a continuing threat to land and water resources and human health in the area and also pose a great economic liability for their removal.

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In this paper, we present Phase I (screening tests) and Phase II (mesocosm tests) of a multitask effort for achieving biological closure of an abandoned hazardous waste site situated on the Mississippi River. Biological closure is achieved through *in situ* biological treatment (ISBT), a method which favors the growth of the adapted indigenous microflora in the soil and so promotes the degradation of the toxicants. Waste materials from the site were evaluated for biodegradative potential and acute toxicity of leachate. The validity of the Phase I tests for establishing biotransformation/biodegradation kinetics and leachate toxicity were documented in subsequent Phase II laboratory mesocosm studies.

The selected approach, *in situ* biological treatment, is consistent with the National Contingency Plan to provide the lowest cost alternative which provides a permanent remedy for existing or potential threat to public health and environment. On-site biodegradation through land treatment was selected as the least expensive alternative ($3 million) and most applicable to the site. This technique consists of spreading and mixing the oily sludges over land. The decomposition of hydrocarbon components is encouraged by the soil microorganisms [*1*].

Materials and Methods

Site Characterization

The hazardous waste site investigated was the "Old Inger" CERCLA (Comprehensive Environmental Response, Compensation and Liability Act of 1980) site located on the east bank of the Mississippi River in Louisiana, about 4.5 miles north of the city of Darrow. It is an abandoned oil reclamation facility that was operated between 1967 and 1978. As part of the operation of the plant, sludges were stored in a large open lagoon and buried in a shallow pit; some wastes were spilled into the adjacent swamp. In March 1978, a large spill contaminated a total of 16 acres of the surrounding area. Failure by the owner to clean up the site resulted in the formal declaration by the Louisiana Environmental Control Commission in June 1981 that the site was abandoned.

The wastes identified at the site were consistent with the nature of the oil reclamation plant. They were mixtures of oil refinery oils, motor and automobile oils, and lube oils. As is typical of waste oils, hazardous priority pollutants such as benzene, toluene, and polycyclic aromatic hydrocarbons (PAHs) were present. No polychlorinated biphenyls (PCBs) were found; very low levels of chlorinated hydrocarbons and low levels of heavy metals were found. Tables 1 and 2 present analyses of the "pure wastes," classified as buried waste and lagoon waste, and river silt (control). All were directly collected from the site. By means of gas chromatography (GC) elution time and gas chromatography/mass spectroscopy (GC/MS), 24 PAHs were identified (F-2 fraction, Table 1) and 22 aliphatic hydrocarbons (F-1 fraction, Table 2). Quantitation was by external standard GC in all cases. Detection limit for both fractions was 100 ppm due to the large dilution factors and the lower response factors of the higher molecular weight components. The detection limit for the control soil, however, was 1 ppm.

Microbial Density

The Standard Plate Count Method (SPC) is a direct quantitative measurement of the viable aerobic and facultative anaerobic microflora. Four general groups of microorganisms, that is, bacteria, actinomycetes, yeasts, and filamentous fungi, were enumerated using colony forming units (CFU) and SPC. Replicate 1.0-mL aliquots were inoculated on Jensen's agar medium [*2*] supplemented with 40 μg/mL cycloheximide (Sigma) to inhibit growth of filamentous fungi. Filamentous fungi and yeasts were enumerated on Martin's agar medium [*3*] with 30 μg/mL

TABLE 1—*Primary F-2 constituents in CERCLA waste site (Inger Oil Refinery, Darrow, LA).*

Compound	Buried Wastes	Lagoon Wastes	River Silt (Control)
1. Naphthalene	920	1500	...
2. 1-methylnaphthalene	1200[a]	1700[a]	...
3. 2,3-dimethylnaphthalene	600[a]	1000[a]	...
4. 2,3,5-trimethylnaphthalene	600[a]	700[a]	...
5. Biphenyl	1700[a]	1600[a]	...
6. Fluorene	850	1300	...
7. Dibenzothiophine	800[a]	1200[a]	...
8. Phenanthrene	4528	5757	trace
9. Anthracene	2257	3227	trace
10. 1-methylphenanthrene	800[a]	600[a]	...
11. Fluoranthrene	930	1686	...
12. Pyrene	830	1059	trace
13. Benzo(a) anthracene	470	570	trace
14. Chrysene	340	550	trace
15. Benzo(b) fluoranthrene	ND	ND	trace
16. Benzo(e) pyrene	ND	60	...
17. Benzo(a) pyrene	<100[b]	215	...
18. Perylene	...	...	...
19. Acenapthene	2300	1466	...
20. Substituted benzene	1500[a]	2100[a]	...
21. Indenopyrene	1100	321	...
22. Benzo(g,h,i) perlene	1200	1432	...
23. Dibenzo(a,h) anthracene	100+	357	...
24. Benzo(k) pyrene	ND	457	...
25. Unknown (E.T. = 24.51)	ND	...	<1 ppm

NOTE: Concentration in ppm, [a] semiquantitative, [b] confirmed by GC/MS. Trace = <1 ppm, detection limit 100 ppm for lagoon and buried waste, detection limit 1 ppm for river silt. ND = not detected; E.T. = elution time.

streptomycin (Sigma) and 30 μl/mL chlortetracycline (Sigma) to retard bacterial growth. All plates were incubated for four days at 30°C. Bacteria and actinomycetes were counted on a Biotran III Automatic Colony Counter (New Brunswick Scientific). Yeasts and fungi were enumerated manually.

Adenosine 5' Triphosphate (ATP)

A modification of adenosine 5' triphosphate (ATP) assay as advanced by Holm-Hansen and Booth [*4*], and further presented by Van de Werf, Verstraete [5], and Karl [*6*], was used for determination of microbial biomass. 1.0-g aliquots from all mesocosms (wet weight) were transferred into dilution bottles containing 99-mL sterile distilled and deionized water, homogenized on a homogenizer (Janke & Kunkel Ultra Turrax SD 45) for about 45 s. A 100-μL aliquot of that suspension was then transferred to a 3-mL plastic vial. The vial was inserted into a Lumac 3M Biocounter (Biocounter M2010, Lumac Systems, USA); 100μL of buffer and 100-μL NRB reagent (Nucleotide releasing agent for bacterial cells) were added. ATP was released from microbial cells by adding NRB to a 100-μL sample. After application of the reagent, ATP was measured using the following reactions:

$$\text{luciferin} + \text{luciferase} + \text{ATP} - \text{Mg}^{++} \rightarrow (\text{luciferin} + \text{luciferase} + \text{AMP}) + \text{pp}_i$$

$$(\text{luciferin} + \text{luciferase} + \text{AMP}) - \text{O}_2 \rightarrow \text{decarboxyluciferin} + \text{luciferase} + \text{CO}_2 + \text{AMP} + \text{light}$$

TABLE 2—*Primary F-1 constituents in CERCLA waste site (Inger Oil Refinery, Darrow, LA).*

Compound	Buried Wastes, ppm	Lagoon Wastes, ppm
C-12	800	2300
C-13	1100	3600
C-14	1100	4000
C-15	1400	4300
C-16	1700	5000
C-17	1400	4400
Pristane	4300	3100
C-18	1200	4900
Phytane	2700	1500
C-19	750	3300
C-20	370	2900
C-21	240	2000
C-22	*a*	1400
C-23	*a*	840
C-24	*a*	600
C-25	*a*	890
C-26	*a*	300
C-27	*a*	320
C-28	*a*	*b*
C-29	*a*	1200
C-30	*a*	560
C-31	*a*	330

[a] Below detection limit of 100 ppm.
[b] Lab contaminant.

Following the injection of 100 μL of a luciferin luciferase solution (Lumit, Lumac systems) into the vial, light outputs expressed as relative light units (RLU) were determined over a 10-s integration period. Relative light units were expressed as μg ATP/g dry net weight using standardized 10-μL aliquots of a known ATP standard. Quench corrections for each environmental sample were established with 100-μL aliquots of ATP standard/buffer added in place of the 100-μL buffer addition.

Microtox™

Acute toxicity assessment of waste/soil water soluble fractions (WSF) was determined, following procedures outlined by Matthews et al. and further described in the EPA "Permit Guidance Manual on Hazardous Waste Land Treatment Demonstrations" [7]. A maximum acceptable initial loading rate was determined by calculating the EC_{50} and 95% confidence intervals for the raw waste WSF. The lower EC_{50} limit for the confidence interval provides the upper loading rate for waste/soil toxicity testing. In this case, the EC_{50} was the volume % of the distilled deionized water (DW) extract effecting a 50% decrease in bioluminescence of the marine luminescence bacterium *Photobacterium phosphoreum* during a 5-min test period. The DW extract was obtained by shaking 400-mL DW + 100-g sample for 24 h. All samples were analyzed on a Beckman Microtox Model 2055 toxicity analyzer.

Soil/waste Chromatographic Analyses

The principal analysis performed involved determination of aliphatic (F-1) and aromatic hydrocarbons (F-2). Equal amounts of the waste/soil mixture were used to form a composite. Two

grams of that composite were extracted with 10 mL of Dichloromethane (DCM), and a portion of the extract was placed on a silica gel column. The column was eluted, first with hexane to remove and trap the aliphatics (F-1) and then with 30% DCM in hexane to elute the polynuclear aromatics (PAH). The two liquid fractions were analyzed in a GC flame ionization detector (FID) (Hewlett Packard 5890, equipped with a 50-m by 0.32-mm DB-5 phenyl methyl silicone capillary column). Each compound peak was quantitated and identified by GC/MS (Hewlett Packard 5970B), and the identities of several unknowns were elucidated in this manner. A complete protocol for GC determination of the F1 and F2 constituents is presented in Ref *8*.

Experimental Design

Screening Tests

Optimal loading rates for the CERCLA site soil/wastes were determined on the basis of both indigenous microbial population performances and acute toxicity leachate analysis.

The described investigations for ISBT involved three major correlative aspects as depicted in Fig. 1. The screening tests consisted of a series of experimental mesocosms with mixture of Mississippi River silt and top soil (sandy clay). Soil mixtures Type I and Type II consisted of one part river silt and two parts top soil, and two parts river silt and one part top soil, respectively. The soils were collected from uncontaminated areas near the contaminated site and air dried prior to analyzation. The soils were passed through a No. 10 sieve (Soiltest, Inc.) to remove larger particles and plant residues, and also to render them more homogenous. Soil Type II was found to be unsuitable because of its lower EC_{50}, detected by the EPA research laboratory in ADA, Oklahoma. Soil Type I, therefore, was selected for the course of the experiment. The loading rates of the wastes mixed with soil Type I were 2, 4, 8, and 12% by weight (based on percent oil and grease) for both lagoon and buried waste. No nutrient amendment was added. The highest level of microbial activity, evaluated 2 h after mixing and reevaluated over a period of 17 days after mixing, determined the optimal loading rate for each waste type.

Mesocosm Tests

After optimum toxicant loading determination, Phase II was set up, a battery of 21 mesocosms to evaluate biotransformation processes under the selected loading rates. Together with the loading of wastes, each mesocosm received a nutrient amendment consisting of 4.0 g KH_2PO_4, 2.0 g K_2HPO_4, 1.0 g $MgSO_4$, and 0.5 g KNO_3 × 4.5 kg^{-1} soil mixture, respectively. Nutrient amendments were incorporated into the mesocosm by hand mixing with the soil mixture and the waste at Day 0. A second nutrient amendment consisting of 2.0 g KH_2PO_4, 2.0 g K_2HPO_4, 1.0 g $MgSO_4$, and 0.5 g KNO_3 × 4.5 kg^{-1} soil mixture, respectively, followed on Day 27. The percent moisture was also adjusted on Day 27 to >10%. Since microbial oxidation of PAH requires molecular oxygen, the whole contents of the mesocosms were remixed weekly to promote oxygenated conditions.

Field Verification Studies

The pilot verification study involved the setup of five 12 × 50 × 2-ft. plots at the Old Inger site. The plots were filled with soil Type I and sequentially loaded with the two waste types. Plot 1 (control) did not receive any toxicant loading. Plots 2 and 3 (Group I) were loaded twice, first with 4% and then with 2.5% buried waste. Plots 4 and 5 (Group II) received four sequential waste loadings of the following type: 4% lagoon, 2.5% lagoon, 2.5% buried, and 2.5% buried waste. There were about six weeks between each application for Group II. At the first application, the

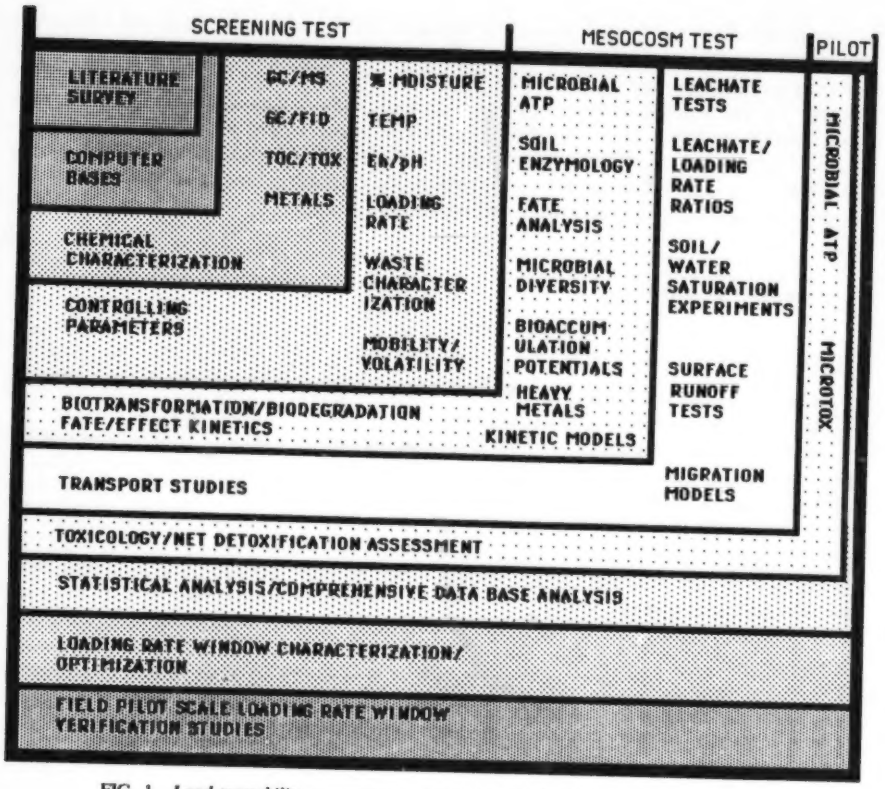

FIG. 1—*Land treatability assessment protocol for EPA-listed hazardous waste sites.*

plots were seeded with adapted microorganisms isolated from the site and cultivated in the laboratory. Between each treatment, the plots were tilled and sampled to a depth of 6 in.

Results and Discussion

Screening Tests

Optimal loading rates for the CERCLA site soil/wastes were determined by careful evaluation of both indigenous microbial population performance and acute toxicity leachate analysis. Microbial ATP showed initial stress on the indigenous microbial populations through Day 10 for both waste types (Fig. 2). However, the microbial population showed recovery by Day 17. Lagoon wastes, applied at 2% and 4%, showed minimal stress and increased microbial ATP levels by Day 17. Buried wastes showed comparable results for 2 to 4% waste loadings at Day 17. Microbial diversity indices agreed with ATP estimates, which suggested a maximum loading rate of 8% for lagoon wastes and 2 to 4% for buried wastes (Fig. 3). EC_{50} levels of leachates (Fig. 4) predicted 3.0 to 9.0% waste weight (wet basis) for lagoon waste and 3 to 6.0% waste weight (wet basis) for the

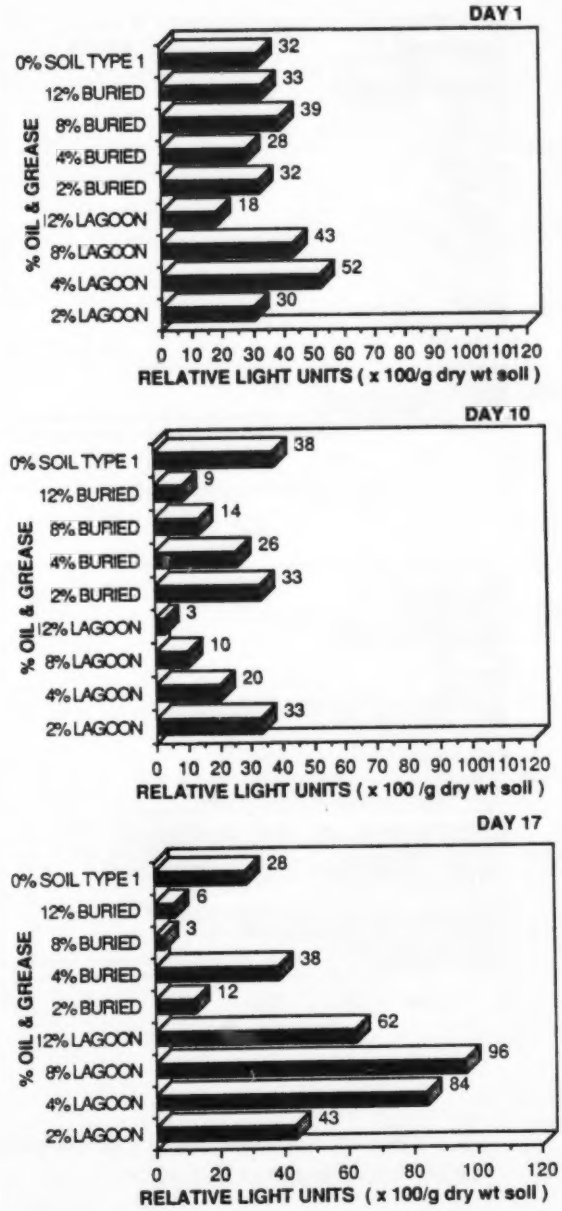

FIG. 2—*Microbial ATP profile of screening test microcosms.*

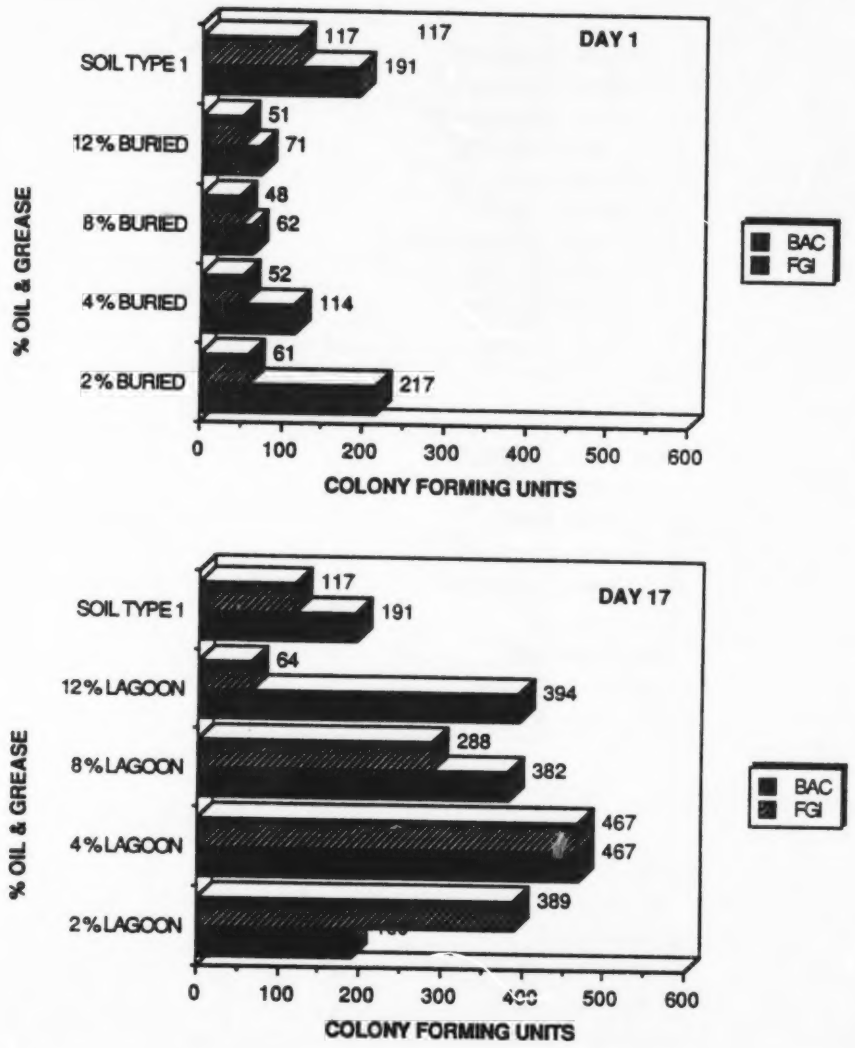

FIG. 3—*Microbial density of screening test mesocosms.*

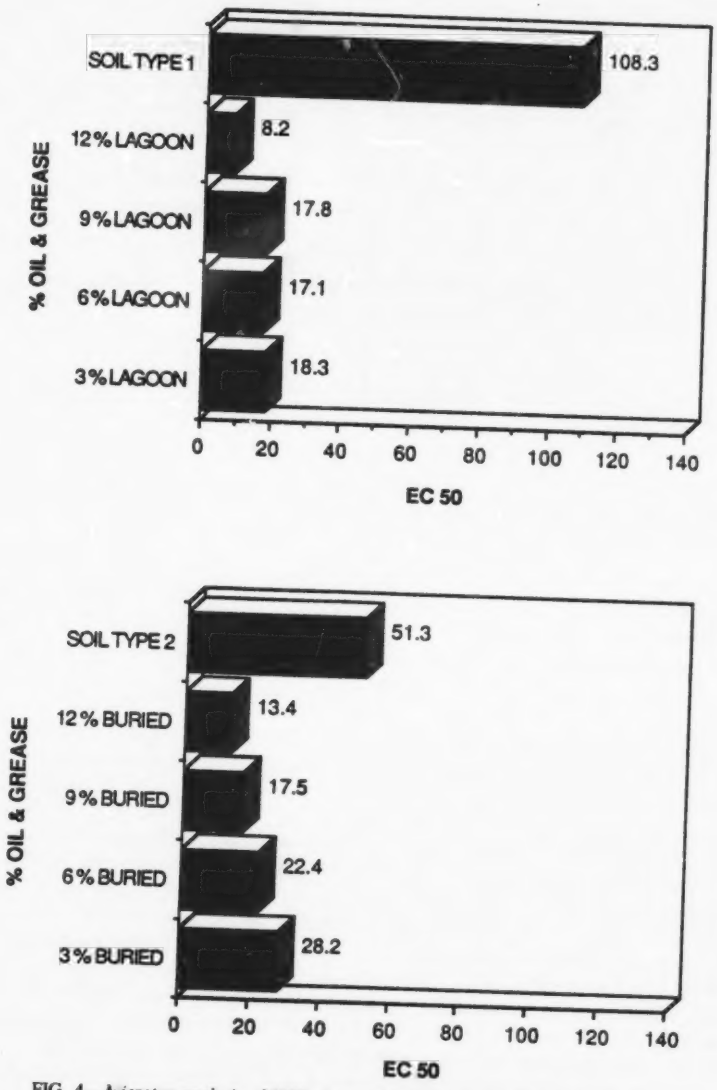

FIG. 4—*Microtox analysis of WSF of screening mesocosm soil/waste loading.*

buried waste. A loading rate of 4% for lagoon waste and 2.5% for the buried waste was found to be the mean acceptable loading rate for the Phase II mesocosm studies.

Mesocosm Tests

Manuscript limitations prevent the showing of all of the data; therefore, for the following results, only lagoon waste was selected for presentation. Figure 5 shows GC/FID chromatograms of the

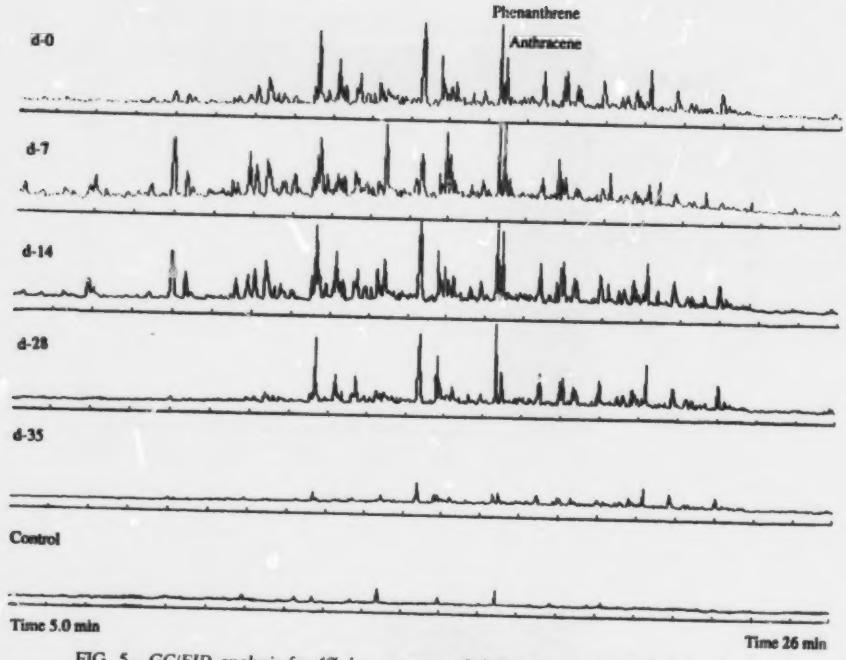

FIG. 5—*GC/FID analysis for 4% lagoon waste, F-2 fraction over a 35-day time frame.*

F-2 fractions for lagoon waste mesocosms with a 4% loading rate and the control soil. All compounds show a decrease over the 35-day incubation period. The total gross removal over this time period was almost 70%. Figure 6 represents GC/FID chromatograms for the aliphatic fraction (F-1) for 4% lagoon mesocosms over the same time frame. Table 3 gives the component concentrations of the F-1 fraction in ppm. The increases in concentrations for C-17, pristane, and C-18 at Day 28 are probably due to sample variability. The total removal was 90.85% The same degradation pattern, but at a faster rate, was observed for the 2.5% lagoon waste loading (Fig. 7). The total removal for the 2.5% loading F-2 fraction was 96.95% (Table 4).

The kinetics of toxicant disappearence for lower molecular weight PAHs, especially naphthalene, cannot be completely attributed to a microbial biotransformation scenario, but may also involve the high volatility of these compounds. Moderate abiotic losses of these PAHs due to volatility has been reported extensively [*1*], but is believed to not be substantial. Photooxidation of the PAHs was minimized in the mesocosm tests by incubating the experimental units, covered, in the dark. However, some unidentified abiotic mechanisms of PAH loss probably occurred. Additional investigations into identifying intermediate abiotic transformation processes are underway.

Conclusions

Optimal toxicant loading rates windows, determined in screening tests, were shown to be acceptable for inducing microbial biotransformation/biodegradation in mesocosm units and minimizing acute leachate toxicity. The above studies for all of the compounds analyzed exhibited a decrease in concentration over time for both laboratory and field studies. The decreases were

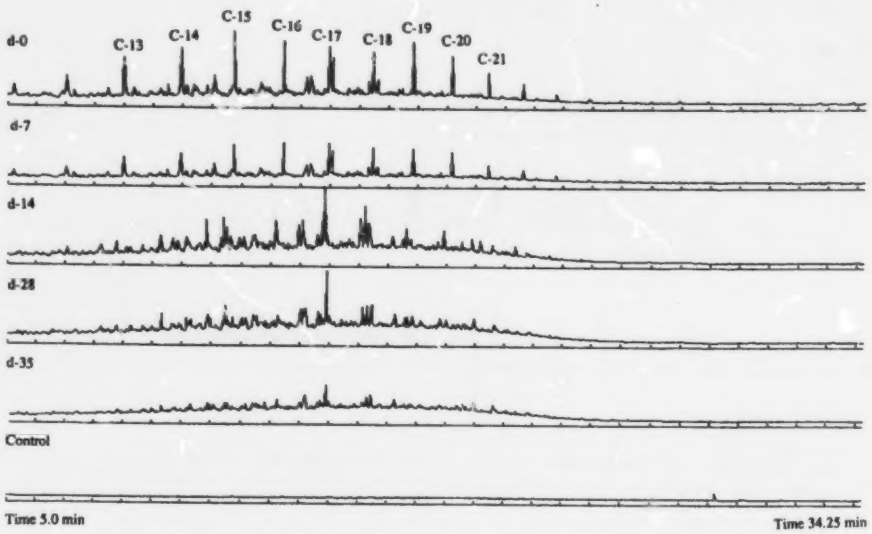

FIG. 6—*GC/FID analysis for 4% lagoon waste, F-1 fraction over a 35-day time frame.*

TABLE 3—*F-1 fraction; 4% lagoon waste.*

Compound	Incubation Period, Days				
	0	7	14	28	35
C-11	83	44	<3.5	<3.5	<3.5
C-12	119	58	40	<3.5	<3.5
C-13	236	113	42	14	<3.5
C-14	202	101	43	19	<3.5
C-15	214	108	10	47	18
C-16	249	133	18	8	6
C-17	221	115	35	217	91
Prystane	141	94	17	29	15
C-18	227	127	140	143	49
Phytane	71	54	14	12	8
C-19	167	91	42	33	21
C-20	135	78	28	<3.5	<3.5
C-21	93	53	8	<3.5	<3.5
C-22	57	34	4	<3.5	<3.5
C-23	29	17	<3.5	<3.5	<3.5
C-24	17	10	<3.5	<3.5	<3.5
C-25	11	7	<3.5	<3.5	<3.5
[a] Total (Gross)	2272	1237	441	522	208

NOTE: Min detection limit 3.5 ppm.
[a] Total of each column, concentration in ppm.

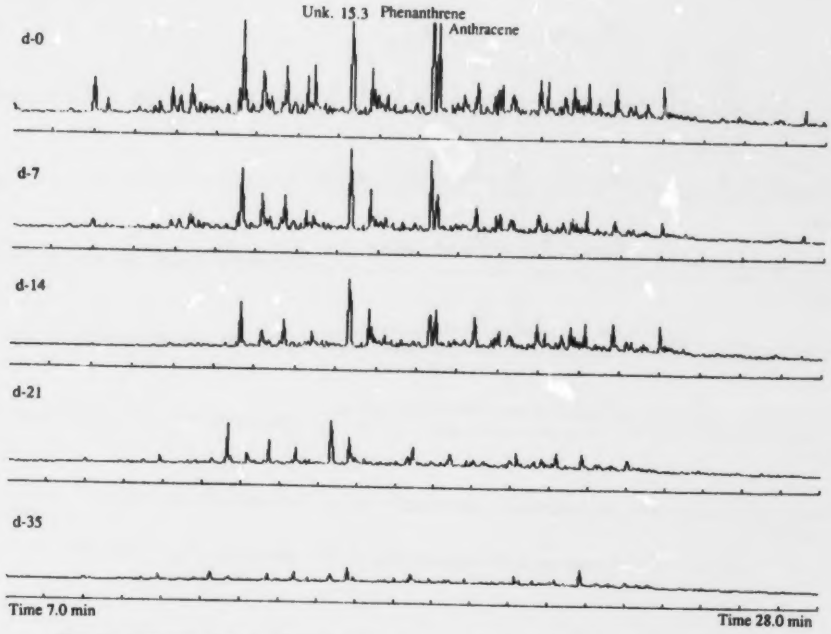

FIG. 7—*GC/FID analysis for 2.5% lagoon waste, F-2 fraction over a 35-day time frame.*

mostly attributed to microbial activity of the indigenous soil microflora. However, undefined abiotic losses were noted and need to be further studied. Both waste types, the lagoon and buried wastes, at both loading rates, 2.5% and 4%, were degraded by the indigenous microflora. As compounds were degraded by microorganisms, the metabolites identified were generally methyl-substituted homologs, which are generally less toxic than the parent compound and usually not found on priority pollutants or toxic substances lists of EPA. Mutagenicity and carcinogenicity of these intermediate degradation products need to be evaluated.

Partial data sets from the pilot verification study (Phase III) are presented to support screening test and mesocosm test data.

Preliminary data from pilot verification studies is shown in Fig. 8. These GC/FID chromatograms represent the first waste application for both Group I and Group II plots over a 25-day time frame. The first chromatogram of each series shows the soil plots before waste application. Complete differentiation into the two fractions, F-1 and F-2, was not possible. A multiple waste inoculum recovered from a different location at the Inger Site was used. Additionally, the waste contained a lesser amount of PAHs than the one tested in the laboratory. However, the general trend of hydrocarbon reduction as observed in Phase II studies was evident. It is important to know that the residual components shown at Day 25 have been determined by GC/MS to be primarily F-1 straight chain hydrocarbons, respectively C-17 and C-19 aliphatics.

In land-farm soil experiments conducted by Bossert et al. [*1*], analysis of oily sludge at the conclusion of a 1280-day laboratory simulation showed F-2 fractions to have been more rapidly eliminated than F-1 fractions. Although parallels can be drawn between our field experiment, the F-2 fraction constituted only a small portion of the total hydrocarbons present; 47% of the total hydrocarbons applied (seven applications) were eliminated in their bioflask study [*1*]. Preliminary

TABLE 4—*F-2 fraction: 2.5% lagoon waste.*

Compound	Incubation, Days				
	0	7	14	21	35
Naphthalene	18.0	>0.1	>0.1	>0.1	>0.1
Methylnapht.	19.0	>0.1	>0.1	>0.1	>0.1
Dimethylnap.	13.0	>0.1	>0.1	>0.1	>0.1
UNK (Rt = 11.1)	28.0	16.0	>0.1	>0.1	>0.1
UNK (Rt = 11.4)	25.0	14.0	1.0	>0.1	>0.1
Trimethylnap.	7.0	0.6	>0.1	>0.1	>0.1
Acenaphthalene	20.0	11.0	3.0	1.6	0.2
UNK (Rt = 12.7)	82.0	64.0	42.0	39.0	1.8
UNK (Rt = 13.2)	48.0	39.0	20.0	15.0	0.2
Biphenyl	19.0	12.0	5.0	1.2	>0.1
Fluorene	30.0	13.0	3.8	>0.1	0.5
UNK (Rt = 15.3)	170.0	120.0	119.0	75.0	13.0
UNK (Rt = 15.8)	50.0	32.0	36.0	25.0	>0.1
UNK (Rt = 15.9)	21.0	>0.1	>0.1	>0.1	>0.1
UNK (Rt = 16.2)	24.0	15.0	12.0	>0.1	>0.1
Dibenzothio.	21.0	8.0	7.0	>0.1	>0.1
Phenanthrene	138.0	68.0	42.0	7.8	1.3
Anthracene	97.0	42.0	38.0	22.0	4.2
UNK (Rt = 18.4)	33.0	36.0	44.0	22.0	3.3
UNK (Rt = 18.9)	27.0	16.0	13.0	2.9	0.3
UNK (Rt = 19.0)	33.0	18.0	18.0	5.2	>0.1
1-Methylphen.	17.0	11.0	12.5	4.4	0.7
UNK (Rt = 19.9)	51.0	33.0	39.0	9.5	>0.1
UNK (Rt = 20.8)	28.0	17.0	22.0	9.0	>0.1
Fluoranthene	37.0	22.0	32.0	14.0	4.0
Pyrene	21.0	11.0	20.0	11.0	13.0
Total (Gross)	1900	860	710	340	58

NOTE: The above numbers are accurate to only 2 significant fig. concentr. in ppm. UNK = unknown; Rt = retention time.

data from our field experiments indicate a net total hydrocarbon removal of 80.34% for Group I and 83.40% for Group II by Day 25. The differences in overall microbial performance in the degradation process of the Phase II and Phase III investigations reported above and those of Bossert et al. [*1*] are due to differences in environmental parameters such as temperature, moisture, soil, microbial diversity/density, and other biotic or abiotic factors.

It is important to emphasize that waste sludges with different F-1 and F-2 content may not necessarily behave similarly under comparable conditions. However, in the above studies, all of the compounds analyzed exhibited decreases in concentration over time for both laboratory and field tests. The final closure activities will probably require one-and-a-half-years time treatment, provided the waste applications and reapplications can be carried out in three-months intervals as presently indicated. The costs of the total procedure are estimated to rise from originally $3 million to now $6 million. Postclosure monitoring of soil and leachate collected from the site is recommended for a time period of 30 years after setup of land-farming facilities.

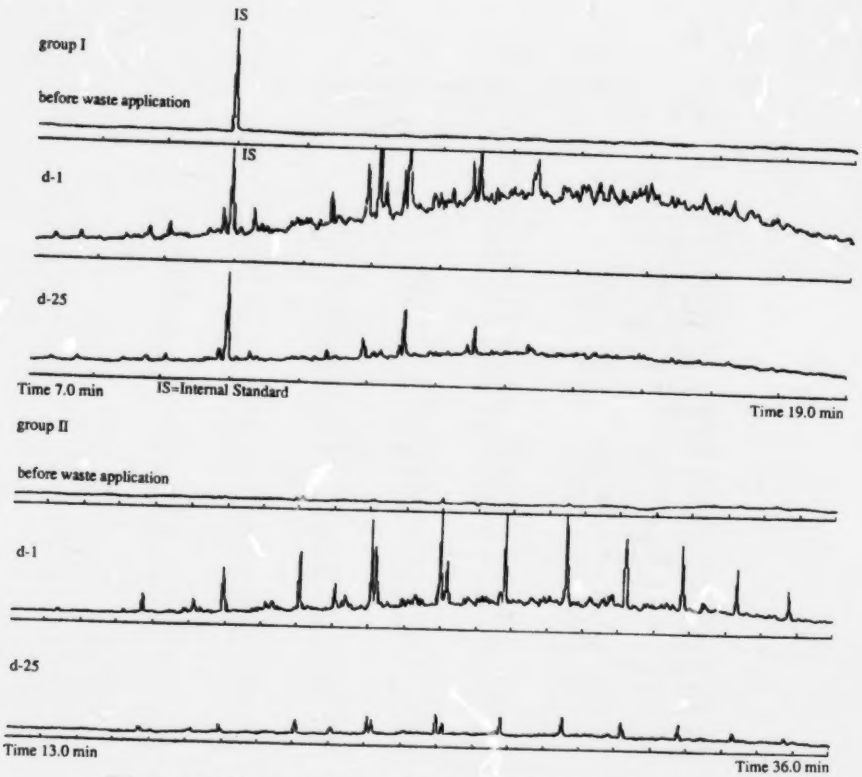

FIG. 8—*GC/FID analysis for Group I and Group II over a 25-day time frame.*

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